PATENT SPECIFICATION

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DRAWINGS ATTACHED

1 221 909

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(54) IMPROVEMENTS IN OR RELATING TO APPARATUS FOR THE HEAT TREATMENT OF ELECTRICALLY CONDUCTIVE MATERIALS

(71) We, STANDARD TELEPHONES AND CABLES LIMITED, a British Company, of 190 Strand, London, W.C.2, England, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to apparatus for the heat treatment of electrically conductive materials, having particular application to the melting and casting of materials that are highly reactive when hot and hence are particularly liable to contamination during heating by the material of which a containing crucble is made.

According to the invention there is provided a crucible having a charge retaining wall formed by a hollow double open ended cluster of tubes of metal of high electrical and thermal conductivity spaced sufficiently closely side by side along at least a part of their length towards one end of the cluster to prevent escape of molten charge material between the tubes and a charge retaining and supporting floor formed by a separate member inserted into said one end of the cluster and withdrawable therefrom.

For the purposes of this specification a metal of high electrical and thermal conductivity is defined as a metal having a thermal conductivity of not less than 0.49 gram calories per sec. per cm.^{2} per °C per cm. and a specific electrical resistance of not more than 2.665×10^{-6} ohms per cm.^{2} at 0°C. Silver, gold and copper are suitable metals, silver being preferred since it can be highly polished to reduce the loss of heat from the charge by radiation. Alloys of these metals may be employed, or a surface coating of one metal such as silver on a member made of another metal such as copper.

Preferred embodiments of the invention will now be described with reference to the accompanying drawings, in which:—

Figs. 1 and 2 are a sectioned elevation and a plan view respectively of a first form of crucible, with Fig. 1 showing the section along line X—X of Fig. 2,

Fig. 3 is an underneath plan view of a second form of crucible,

Fig. 4 is an elevation of a third form of crucible,

Figs. 5 and 6 show stages in using any of the three forms of crucible to form an ingot from the crucible charge material.

Each form of crucible to be inserted is constructed from silver plated copper tubes of 5/16 inch outside diameter and 0.030 inch wall thickness. Each form of crucible has a charge containing wall formed by a hollow double open ended cluster of such tubes spaced sufficiently closely side by side (e.g. 1/16 inch apart) along at least a part of their length towards one end of the cluster, to prevent molten charge material escaping between the tubes with their axes vertical around the periphery of the crucible. Each form of crucible has a charge retaining and supporting floor formed by a separate member inserted into the said one end of the cluster and withdrawable therefrom.

Referring now to Figs. 1 and 2, the first form of crucible comprises a hollow double open ended cluster of tubes 1 spaced sufficiently closely side by side along a part *l* of their length towards one end of the cluster to prevent molten crucible charge material escaping between the tubes.

The crucible is shown in its vertical oper-

ating position, and at the lower end of the closely spaced tube length *l*, is a separate pedestal 2 inserted into the cluster to form the charge retaining and supporting floor of the crucible. As will be described later, this pedestal, at its upper surface, is in direct contact with molten charge material, and is, at least at its upper (i.e. floor forming) surface, of suitably resistant material. Such suitably resistant material may be refractory material, material which is the same as that of the charge, or a metal of high electrical and thermal conductivity, for example silver plated copper as the tubes. If of such a metal, the pedestal also includes means for fluid cooling this metal floor surface, as by constructing the floor forming part 3 of the pedestal as a hollow silver plated copper shell, with inlet and outlet cooling fluid (e.g. water) feeds into the shell contained in the stem 4 of the pedestal.

The tubes 1 at the lower end of the cluster are splayed to facilitate insertion of the pedestal and the tubes 1 are closed at this lower splayed end of the cluster.

Above the closely spaced tube length *l* the tubes 1 may continue so closely spaced, but preferably are formed outwardly as shown in Fig. 1 to enlarge the cluster to provide an increased volume for containing solid charge material. Clearly the maximum side by side spacing of the tubes should not exceed the minimum particle or lump size of the initial charge material.

At the top end of the crucible is an annular cooling fluid manifold 5 with an inlet 6 and an outlet 7 communicating respectively with an inlet chamber 8 and an outlet chamber 9 formed by an annular dividing plate 10.

Each of the upper ends of the tubes 1 communicate with the inlet chamber 8, and each of the tubes 1 contains a narrower tube 11 which communicates at its upper end with the outlet chamber 9. Each of the tubes 11 extends down its respective containing tube 1 to terminate open ended short of the closed end of the tube 1 so that cooling fluid may pass down the tube 1 and back through the inner tube 11.

The crucible is charged through the aperture 12 in the manifold 5.

Fig. 3 shows a second form of crucible which generally resembles that shown in Figs. 1 and 2, having a hollow double open ended cluster of tubes 31 sufficiently closely spaced side by side along at least a part of their length to prevent molten crucible charge material escaping between the tubes, a withdrawable floor forming pedestal 32 inserted into the splayed lower end of the cluster, and a top cooling fluid manifold 33, but in this form of crucible each adjacent pair of tubes of the cluster forming the crucible charge retaining wall is formed by a single tube communicating at each end with the manifold, one end with the inlet side and the other end with the outlet side, each single tube being bent as shown at 34 at the lower end of the crucible.

In the third form of crucible shown in Fig. 4, the closely spaced tube length splayed lower end, pedestal floor and cooling manifold are as already described for the crucible shown in Figs. 1 and 2 and like references have been used. Since, as already mentioned, the spacing of the tubes 1 in the upper portion of the crucible must be such as to contain the initial charge material, in order to obtain a further increase in initial charge containing volume additional tubes 41 are inserted one between each of the outwardly formed tubes 1 above the closely spaced tube length of the crucible.

Each of these additional tubes 41 communicates at its upper end with the inlet part of the cooling manifold 5 and is closed at its lower end to terminate in a shaped end 42 tapering into the general inward shaping of the tubes 1. Each additional tube 41 contains a narrower tube 43 communicating at its upper end with the outlet side of the manifold and terminating open ended short of the lower closed end of the containing tube 41 so that cooling fluid may be passed down the tube 41 and return through the inner tube 43.

In all the above described forms of crucible, the wall forming tube lengths may be flattened, at least over the closely spaced tube length of the crucible, on the inside and the outside from a circular section to provide, for a given tube starting diameter, a larger molten charge containing volume diameter.

When a crucible of one of the forms described above is incorporated in apparatus for the heat treatment of electrically conductive materials, a primary induction coil 50 (Fig. 5) encircles the crucible 52 around the closely spaced tube length *l* of the crucible to serve as a source of high frequency current when connected to a suitable power supply (not shown) to establish circumferential circulating currents in each of the tubes forming the crucible wall, through which cooling fluid, e.g. water, is circulated via the cooling manifold 53, and in a charge 54 of conductive material in the crucible, so that the charge is heated over a narrow horizontal zone 54A above the charge melting point.

The crucible floor forming pedestal 55 is located within the lower end of the closely spaced tube length *l* with the charge 45 resting thereon so that on formation of the melted zone, this zone has its lower surface contiguous with the floor surface of the pedestal 55.

The magnetic fields due to the circulating currents induced in the wall of the crucible and hence in the charge result in mutual repulsion between the molten charge zone 54A and the adjacent tube surfaces of the crucible. If the current density is sufficiently high the charge is forced away from the adjacent crucible surfaces, and this absence of contact between molten charge and crucible greatly reduces the heat loss from the charge and also virtually eliminates the possibility of charge contamination by the crucible material.

The apparatus may also include means, such as a quartz envelope (not shown) for enclosing the crucible within a suitable atmosphere, e.g. inert, or reducing as hydrogen for a charge of chromium. The apparatus may further include a solid charge hopper (not shown) located above the crucible for feeding the crucible with fresh charge material, as indicated by twin arrows 56.

The apparatus also includes means, such as a powered linear shaft drive, for effecting continuous downward withdrawal of the pedestal 55 out of the crucible. This withdrawal is commenced once the horizontal molten zone 54A has been established. As the charge supporting floor drops, the charge drops with it, and away from the induction coil with the result that the lowest portion of the charge solidifies.

As the pedestal is withdrawn out of the bottom of the crucible, the continuously solidifying lower portion of the charge, 54B in Fig. 6, effectively functions as a plug to retain the remainder of the charge within the crucible.

This plug constitutes a solid ingot of the charge material, being formed by withdrawal of the pedestal a required distance from the crucible. The charge level in the crucible may be maintained by fresh charge from the hopper, and the charge material in the crucible is continuously passed through the induction coil to be melted and then to be solidified into the plug portion 54B.

When an ingot of the required length has been formed, the power is switched off and the ingot removed. The pedestal is removed from the end of the ingot, as by cutting close to the end of the ingot if the pedestal surface is of the same material as that of the ingot or possibly if the pedestal floor surface is of refractory material to remove any trace of impurity therefrom.

WHAT WE CLAIM IS:—

1. A crucible having a charge retaining wall formed by a hollow double open ended cluster of tubes of metal of high electrical and thermal conductivity spaced sufficiently closely side by side along at least a part of their length towards one end of the cluster to prevent escape of molten charge material between the tubes and a charge retaining and supporting floor formed by a separate member inserted into said one end of the cluster and withdrawable therefrom.

2. A crucible as claimed in claim 1 in which the tubes are splayed at said one end of the cluster.

3. A crucible as claimed in claim 1 or 2 in which at least the floor surface of said member is of refractory material

4. A crucible as claimed in claim 1 or 2 in which at least the floor surface of said member is of the same material as the crucible charge material.

5. A crucible as claimed in claim 1 or 2 in which at least the floor surface of said member is of a metal of high electrical and thermal conductivity, and in which said member includes means for fluid cooling said metal floor surface.

6. A crucible as claimed in any one of claims 1 to 5 comprising an annular manifold connected to the tubes at the other end of the cluster.

7. A crucible as claimed in claim 6 in which the cluster is formed by separate tubes each closed at the said one end of the cluster and each containing a narrower tube connected to the manifold and terminating open ended short of the closed end of its containing tube.

8. A crucible as claimed in claim 6 in which the cluster is formed by bent tubes each connected at each end thereof to the manifold.

9. A crucible as claimed in any one of claims 1 to 8 in which said cluster is enlarged towards the said other end beyond the molten charge containing length.

10. A crucible substantially as described and as shown in Figs. 1 and 2, or in Fig. 3, or in Fig. 4 of the accompanying drawings.

11. Apparatus for forming an ingot of electrically conductive material including a crucible as claimed in any one of claims 1 to 10, means for passing cooling fluid through the crucible tubes, a primary induction coil surrounding the closely spaced tube length of the crucible, and means for effecting withdrawal of the floor forming member from an initial location within the closely spaced tube length out of the cluster through said one end.

12. A method of forming an ingot of electrically conductive material which includes the steps of charging the material into the crucible claimed in any one of claims 1 to 10, passing cooling fluid through the crucible tubes, rendering molten by a primary induction coil surrounding the closely spaced tube length of the crucible that portion of the charge contained therein, and withdrawing the floor forming mem-

ber of the crucible from an initial location within the said closely spaced tube length out of the cluster through said one end.

13. Apparatus for forming an ingot of electrically conductive material substantially as described and as shown in Figs. 5 and 6 of the accompanying drawings.

14. A method of forming an ingot of electrically conductive material substantially as described with reference to Figs. 5 and 6 of the accompanying drawings.

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1221909 COMPLETE SPECIFICATION

4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

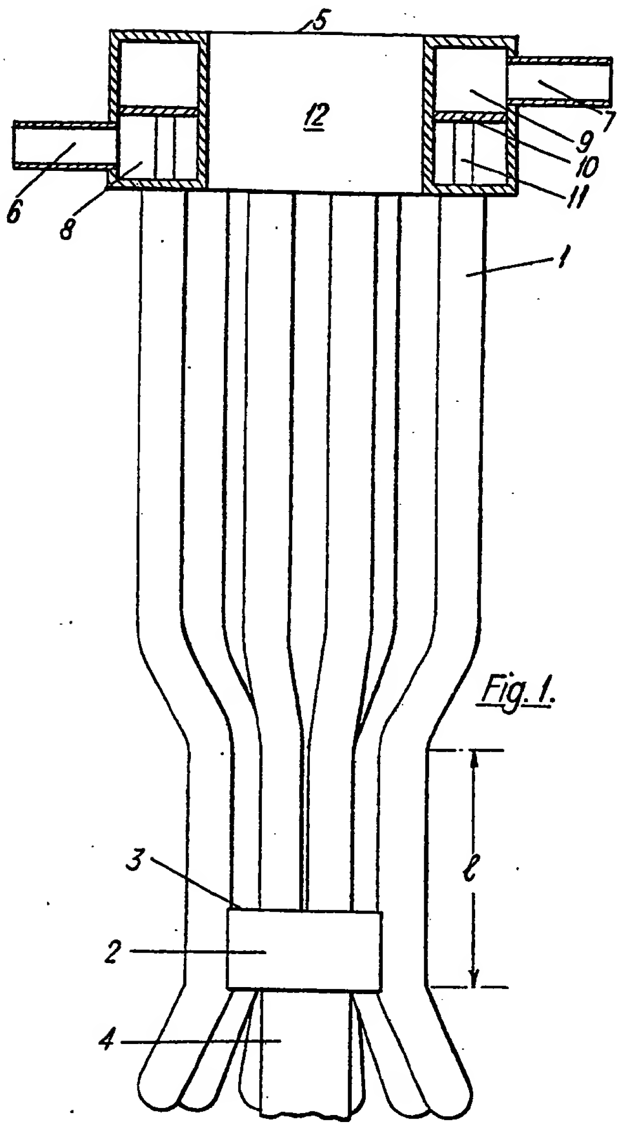

Fig. 1.

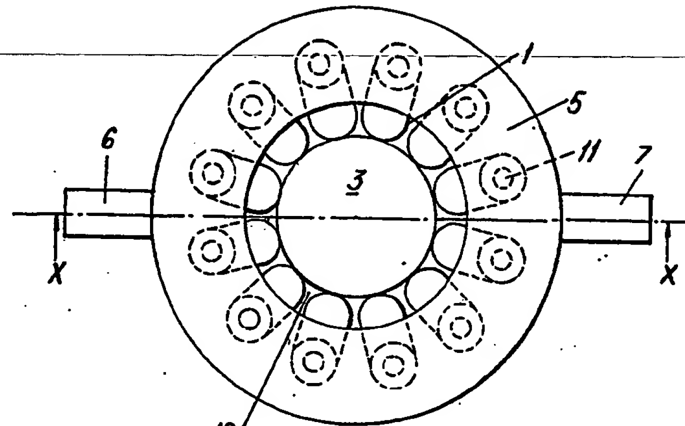

Fig. 2.

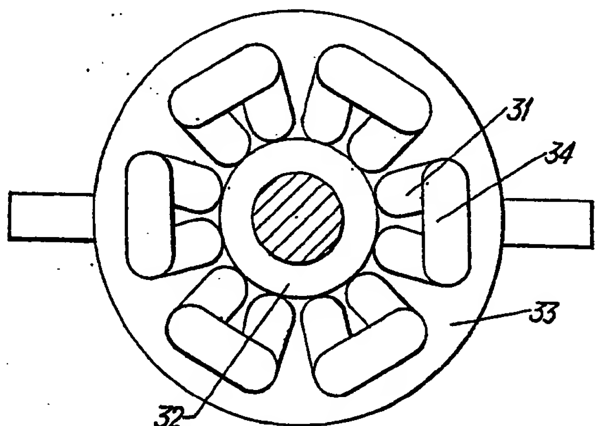

Fig. 3.

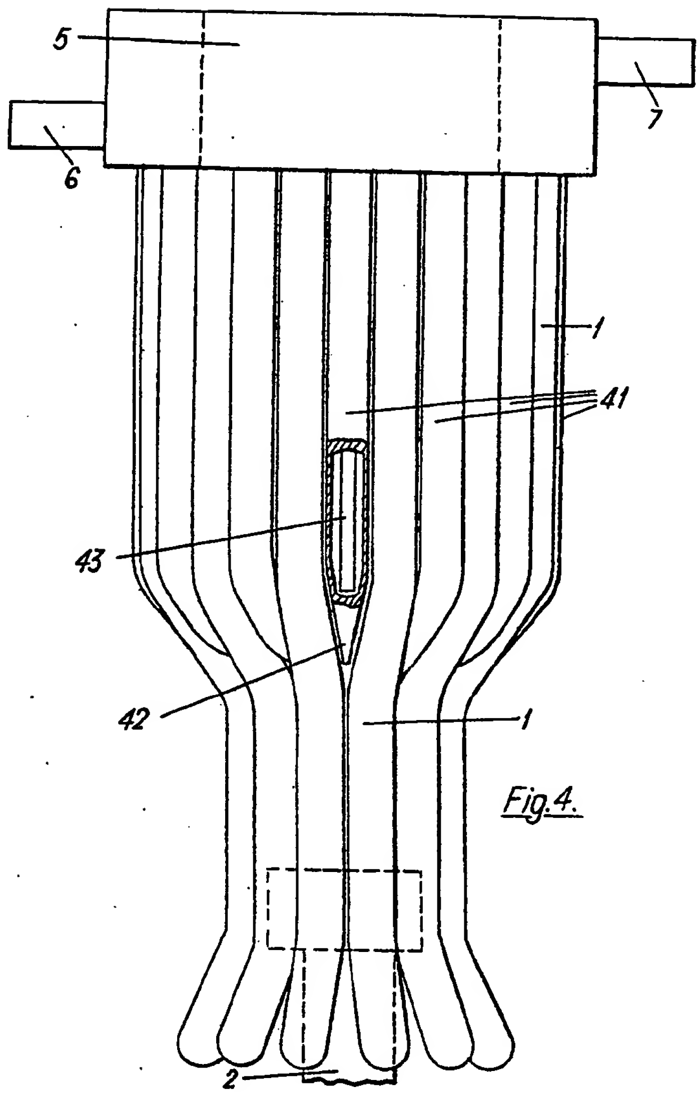

Fig.4.

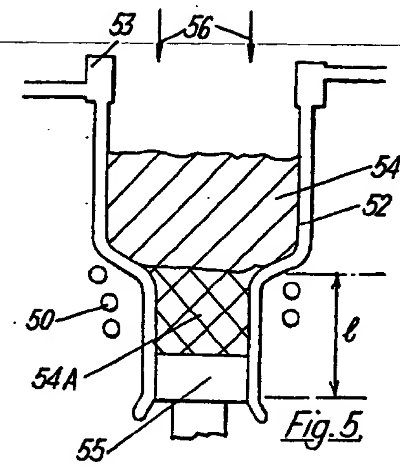

Fig. 5.

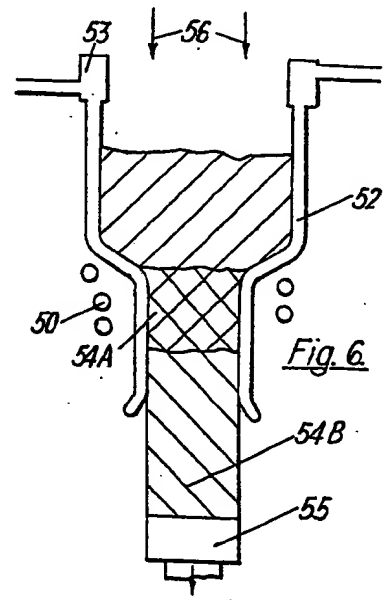

Fig. 6.